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(54) LIGHT SEMICONDUCTOR ELECTRODEPHOTOELECTRIC CONVERSION DEVICE AND PHOTOELECTRIC CONVERSION METHOD

(57)Abstract:

PROBLEM TO BE SOLVED: To improve photoelectric conversion efficiency, stability and durability by providing an adsorbing film by at least one kind of perylene derivative on a base material of a semiconductor.

SOLUTION: A light semiconductor electrode has an adsorbing film by at least one kind of perylene derivative expressed by either of formula I and formula II on a base material of a semiconductor. In the formula I and the formula IIA represents a bivalent group expressed by formula III. In the formula IIIX represents a hydrogen atom, a halogen atom or an alkyl group having the carbon number of 1 to 4. Y represents a group bondable by reacting with the semiconductor and is desirably a group expressed by $-(CH_2)_n-Z$. Here Z is $-COOH$ or $-NH_2$ and (n) is an integer of 0 to 4. Titanium oxide is particularly desirable as the semiconductor from the viewpoint of a photoelectric conversion characteristic, chemical stability and manufacturing facility. The light semiconductor electrode can be manufactured by soaking the base material of this semiconductor in a solution of the perylene derivative expressed by the formula I or the formula II.

CLAIMS

[Claim(s)]

[Claim 1] An optical semiconductor electrode which has an adsorption film by at least one sort of a perylene derivative expressed with either a following general formula (Ia) and a general formula (Ib) on a substrate of a semiconductor and is characterized by things.

A general formula (Ia)

[Formula 1]

General formula (Ib)

[Formula 2]

However A expresses the divalent basis expressed with following general formula (II) among said general formula (Ia) and a general formula (Ib).

General formula (II)

[Formula 3]

However X express the alkyl group of a hydrogen atom a halogen atom or the carbon numbers 1-4 among said general formula (II). Y expresses the basis which reacts to said semiconductor and can be combined.

[Claim 2] the optical semiconductor electrode according to claim 1 whose Y is $-(CH_2)_n-Z$ and a basis come out of and expressed in a perylene derivative expressed with either a general formula (Ia) and a general formula (Ib). However in said basis Z expresses $-COOH$ or $-NH_2$. n expresses an integer of 0-4.

[Claim 3] The optical semiconductor electrode according to claim 1 or 2 whose semiconductor is titanium oxide.

[Claim 4] A photoelectric conversion device which has at least a connecting means which connects an electrode of a couple immersed into an electrolytic solution and an electrode of this couple so that energization is possible and is characterized by one side of an electrode of this couple being the optical semiconductor electrode according to any one of claims 1 to 3.

[Claim 5] In a photoelectric conversion method of making an electrode of a couple mutually connected so that energization was possible immersed into an electrolytic solution and producing a photoelectric conversion reaction by irradiating at least one side of an electrode of this couple A photoelectric conversion method wherein an electrode which

irradiates with said light is the optical semiconductor electrode according to any one of claims 1 to 3.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the optical semiconductor electrode which is efficiently available and is excellent in photoelectric conversion efficiency, stability, endurance etc. and can carry out sunlight by low cost, the photoelectric conversion device using it and the photoelectric conversion method.

[0002]

[Description of the Prior Art] In recent years, use of sunlight attracts attention as an energy resource replaced with fossil fuels such as petroleum and coal. As a photoelectric conversion device which transforms light energy into electrical energy directly, the dry type solar cell in which p-n junction was formed on inorganic semiconductor such as silicon and gallium arsenide is known widely and it is already put in practical use as a power supply of the object for remote places or a portable electronic device etc. However, since the energy and cost which the manufacture takes are very high in the case of said dry type solar cell, there is a problem that it is difficult to use widely.

[0003] The wet solar cell which on the other hand used the photoelectrochemical reaction which occurs by the interface of a semiconductor and an electrolytic solution as another photoelectric conversion device which transforms light energy into electrical energy is known. Semiconductors used in said wet solar cells such as titanium oxide and tin oxide, as compared with the silicon used in said dry type solar cell, gallium arsenide etc., it can manufacture at far low energy and cost and titanium oxide is especially expected as a future energy conversion material from excelling in both sides of a photoelectric transfer characteristic and stability. However, it cannot be said that they can use only the ultraviolet radiation which is about 4% of sunlight but their conversion efficiency is high enough since stable optical semiconductor such as titanium oxide have the band gap as large as not less than 3 eV.

[0004] On the surface of this optical semiconductor as sensitizing dye, then organic coloring matters such as cyanine dye and a xanthene dye, to make organometallic complexes such as a tris(2,2'-bipyridyl) ruthenium (II)

complexadsorband to carry out spectral sensitization is triedit is known that it is a method effective in improvement in conversion efficiency (T. -- OsaM. FujihiraNature. and 264349 (1976).) Brian O'ReganMichael GratzelNature353736 (1991)JP1-220380Aetc.

[0005]Howeverneither cyanine dye nor a xanthene dye is enough in respect of stabilityenduranceetc. and on the other handalthough the organic ruthenium complex is excellent in respect of conversion efficiencystabilityetc. it has the problem of being expensive. Thereforethe actual condition is that high conversion efficiencythe optical semiconductor electrode cheap at high durabilitythe photoelectric conversion deviceand the photoelectric conversion method are not yet provided.

[0006]

[Problem(s) to be Solved by the Invention]This invention solves many problems in said formerand makes it a technical problem to attain the following purposes. That isan object of this invention is to provide the optical semiconductor electrodephotoelectric conversion deviceand the photoelectric conversion method of it being efficiently availableand excelling in photoelectric conversion efficiencystabilityenduranceetc. and carrying out sunlight by low cost.

[0007]

[Means for Solving the Problem]Said The means for solving a technical problem is as follows. That isit is an optical semiconductor electrode which has an adsorption film by at least one sort of a perylene derivative expressed with either a following general formula (Ia) and a general formula (Ib) on a substrate of <1> semiconductorand is characterized by things.

[0008]General formula (Ia)

[Formula 4]

[0009]General formula (Ib)

[Formula 5]

[0010]HoweverA expresses the divalent basis expressed with following general formula (II) among said general formula (Ia) and a general formula (Ib).

[0011]General formula (II)

[Formula 6]

[0012] However X express the alkyl group of a hydrogen atom a halogen atom or the carbon numbers 1-4 among said general formula (II). Y expresses the basis which reacts to said semiconductor and can be combined.

an optical semiconductor electrode given in a claim <1> whose Y is -
(CH₂)_n-Z and a basis come out of and expressed in a perylene derivative expressed with either <2> general formulas (Ia) and a general formula (Ib). However in said basis Z expresses -COOH or -NH₂. n expresses an integer of 0-4.

<3> semiconductors are optical semiconductor electrodes given in the above <1> or <2> which is titanium oxide.

[0013] It has at least a connecting means which connects an electrode of a couple immersed into <4> electrolytic solutions and an electrode of this couple so that energization is possible and one side of an electrode of this couple is a photoelectric conversion device characterized by being an optical semiconductor electrode of a statement from the above <1> at either of <3>.

[0014] <5> In a photoelectric conversion method of making an electrode of a couple mutually connected so that energization was possible immersed into an electrolytic solution and producing a photoelectric conversion reaction by irradiating at least one side of an electrode of this couple. An electrode which irradiates with said light is the photoelectric conversion method characterized by being an optical semiconductor electrode of a statement from the above <1> at either of <3>.

[0015]

[Embodiment of the Invention] (Optical semiconductor electrode) The optical semiconductor electrode of this invention has an adsorption film by at least one sort of a perylene derivative expressed with either a following general formula (Ia) and a general formula (Ib) on the substrate of a semiconductor.

[0016]- Substrate of a semiconductor - As said semiconductor titanium oxide, tin oxide, tungstic oxide, a zinc oxide, indium oxide, niobium oxide, strontium titanate etc. are mentioned for example. These may be used by an one-sort independent and may use two or more sorts together. Especially in this invention the reasons of a photoelectric transfer characteristic, chemical stability, manufacture ease etc. to titanium oxide is preferred also in these.

[0017] There is no restriction in particular about the shape of the substrate of said semiconductor structure and a size and it can choose suitably according to the purpose. In this invention it may be a

substrate which consists only of said semiconductor and may be a substrate which forms the coating membrane of said semiconductor on an electrode with publicly known tabular [by the transparent electrode by ITO glass, soda glass etc., platinum, copper, black lead etc.] or mesh state electrode etc. for example. In the case of the latter substrate, this coating membrane may be provided the whole surface on said publicly known electrode and may be provided in part.

[0018]- Adsorption film - Said adsorption film is formed of at least one sort of a perylene derivative expressed with either a following general formula (Ia) and a general formula (Ib).

[0019] General formula (Ia)

[Formula 7]

[0020] General formula (Ib)

[Formula 8]

[0021] However, A expresses the divalent basis expressed with following general formula (II) among said general formula (Ia) and a general formula (Ib).

[0022] General formula (II)

[Formula 9]

[0023] However, X expresses the alkyl group of a hydrogen atom, a halogen atom, or the carbon numbers 1-4 among said general formula (II). The basis which expresses the basis which Y reacts to said semiconductor and can be combined and is expressed with $-(CH_2)_n-Z$ (here Z expresses $-COOH$ or $-NH_2$.) n expresses the integer of 0-4. It is desirable and especially the basis expressed with $-(CH_2)_n-COOH$ (n expresses the integer of 0-4.) is preferred.

[0024] A desirable example of a perylene derivative expressed with either said general formula (Ia) and a general formula (Ib) is shown below.

[0025] General formula (Ia)

[Formula 10]

[0026] General formula (Ib)

[Formula 11]

[0027]

[Table 1]

[0028] In the perylene derivative expressed with said general formula (Ia) and a general formula (Ib) Z is $-(CH_2)_n-COOH$ (n). The integer of 0-4 is expressed. The perylene derivative which is a basis expressed is compoundable by making a 34910-perylene tetracarboxylic anhydride and the compound expressed with following general formula (III) react.

[0029] General formula (III) [Formula 12]

[0030] However said general formula (III) X express the alkyl group of a hydrogen atom a halogen atom or the carbon numbers 1-4 inside. n expresses the integer of 0-4.

[0031] The perylene derivative which is a basis as which Z is expressed in $-NH_2$ in the perylene derivative expressed with said general formula (Ia) and a general formula (Ib) After making a 34910-perylene tetracarboxylic anhydride and the compound expressed with following general formula (IV) react It is compoundable using reducing agent such as zinc and stannous chloride by changing the nitro group ($-NO_2$) of this general formula (IV) Naka into an amino group ($-NH_2$).

[0032] General formula (IV) [Formula 13]

[0033] However X express the alkyl group of a hydrogen atom a halogen atom or the carbon numbers 1-4 among said general formula (IV).

[0034] In a perylene derivative expressed with said general formula (Ia) and a general formula (Ib) Z is $-(CH_2)_n-NH_2$ (n). An integer expressed with 0-4 is expressed. A perylene derivative which is a basis expressed After making a 34910-perylene tetracarboxylic anhydride and a compound expressed with following general formula (V) react It is compoundable by changing a cyano group ($-CN$) of this general formula (V) Naka into a basis expressed with $-CH_2NH_2$ using reducing agent such as lithium aluminum hydride.

[0035] General formula (V)

[Formula 14]

[0036] However X express the alkyl group of a hydrogen atom a halogen

atom or the carbon numbers 1-4 among said general formula (V). n expresses the integer expressed with 0-4.

[0037] Can manufacture cheaply the perylene derivative expressed with said general formula (Ia) or (Ib) and it is excellent in chemical stability and endurance and is excellent in the holdout in the base material surface of said semiconductor and can carry out spectral sensitization of the optical semiconductor electrode stably and efficient over a long period of time.

[0038] (Production of an optical semiconductor electrode) An optical semiconductor electrode of this invention is producible by making a substrate of said semiconductor immersed into a solution which dissolved at least one sort of a perylene derivative expressed with either said general formula (Ia) and a general formula (Ib) for example. When preparing said solution in order to increase the solubility of said perylene derivative it is preferred to add an alkali or acid in proper quantity into said solution.

[0039] In the case of a perylene derivative which is a basis as which Z is expressed in $-(CH_2)_n-COOH$ (n expresses an integer of 0-4.) as a substance added into said solution an alkali is preferred in a perylene derivative expressed with said general formula (Ia) and a general formula (Ib). As said alkali what can form a salt of said perylene derivativessuch as organic aminesuch as quaternary ammonium hydroxidesuch as inorganic alkalisuch as a potassium hydrateand tetraethylammoniumhydroxideand tetraethyl amineand fusibility is mentioned suitablyfor example. In this invention said perylene derivative may be beforehand prepared as a salt with these alkalis.

[0040] In the case of a perylene derivative which is a basis as which Z is expressed in $-(CH_2)_n-NH_2$ (n expresses an integer of 0-4.) as a substance added into said solution acid is preferred in a perylene derivative expressed with said general formula (Ia) and a general formula (Ib). As said acid what can form a salt of said perylene derivativessuch as organic acidsuch as inorganic acidsuch as chloride and sulfuric acidacetic acidtrifluoroacetic acidand p-toluenesulfonic acidand fusibility is mentioned suitablyfor example. In this invention said perylene derivative may be beforehand prepared as a salt with these acid.

[0041] If a substrate of said semiconductor is taken out after said immersion and it dries after washing with arbitrary solvents an optical semiconductor electrode which an adsorption film by at least one sort of said perylene derivative reacts to a base material surface of said semiconductor and it comes to fix to it will be obtained.

[0042]As a solvent which dissolves at least one sort of a perylene derivative expressed with either said general formula (Ia) and a general formula (Ib)For examplevarious organic solventssuch as amide system solventssuch as ketone solventssuch as alcoholic solventssuch as methanol and isopropyl alcoholacetoneand methyl ethyl ketoneand N.N-dimethylformamideor these mixed solventsare mentioned. These may be used by an one-sort independent and may use two or more sorts together. Also in thesealcoholic solvent is preferred.

[0043]Although at least one sort of adsorption reactions of said perylene derivative to a base material surface of said semiconductor may be performed at a room temperaturethey may be heated to temperature below the boiling point of a solvent if needed.

[0044]An optical semiconductor electrode of this invention produced by making it above can be used conveniently for the following photoelectric conversion devices and photoelectric conversion methods of this invention.

[0045] (Photoelectric conversion device) A photoelectric conversion device of this invention has at least a connecting means which connects an electrode of a couple immersed into an electrolytic solutionand an electrode of this couple so that energization is possible. Said photoelectric conversion device may be provided with apparatus suitably selected according to the purpose etc. outside an electrode of said coupleand said connecting means.

[0046]-A pair of electrodes - One side in an electrode of said couple is an optical semiconductor electrode of said this inventionand another side is a counterelectrode. As said counterelectrodeif electrochemically stablethere will be no restriction in particularand according to the purposeit can choose from a publicly known thing suitablyfor examplecan choose from transparent electrodessuch as flat electrodessuch as platinumgoldand black leador ITO glassand Nesa glassetc. suitably according to the purpose.

[0047]- Connecting means - As long as it has a function in which an electrode of said couple can be connected as said connecting means so that energization is possiblethere is no restriction in particular and can choose suitably according to the purposebut. For examplea wire rod which consists of conductive materialssuch as a publicly known leadvarious metalcarbonand a metallic oxidein itselfa platea printed filmor a vacuum evaporation film is mentioned. This connecting means is connected to an electrode of said couple so that energization is possible. A photoelectric conversion device of the above this invention can be used conveniently for a photoelectric conversion method of the

following this inventions.

[0048] (A photoelectric conversion method) A photoelectric conversion method of this invention makes an electrolytic solution immerse an electrode of a couple mutually connected so that energization was possible and produces a photoelectric conversion reaction by irradiating at least one side of an electrode of this couple. Those in an electrode of said couple who irradiate with light are the optical semiconductor electrodes of said this invention and another side is said counterelectrode. Said connecting means can be used for connecting an electrode of this couple so that energization is possible. For this reason as an electrode of said couple mutually connected so that energization was possible a photoelectric conversion device of said this invention can be used.

[0049]- Electrolytic solution - Although there is no restriction in particular and it can choose suitably as said electrolytic solution For examples salt such as potassium chloride a lithium chloride potassium carbonate and tetraethylammonium perchlorate Nonaqueous solvent solution such as solutions such as acids such as alkalis such as sodium hydroxide and potassium carbonates sulfuric acid and chloride or these mixtures or alcohol and propylene carbonate etc. are mentioned. These may be used by an one-sort independent and may use two or more sorts together. In this invention a compound in which it is the purpose of attaining stabilization of the photoelectric current characteristic and also potassium iodide p-benzoquinone etc. produce an oxidation-reduction reaction reversibly may be added to said electrolytic solution.

[0050] (Photoelectric conversion reaction) In a photoelectric conversion device and a photoelectric conversion method of this invention a photoelectric conversion reaction can be produced as follows. That is an above-mentioned electrode i.e. said optical semiconductor electrode and said counterelectrode of a couple are first immersed into said nature solution of an electric field. Next this optical semiconductor electrode is irradiated with monochromatic light of a 300-650-nm wavelength band white light which includes one in this wavelength band of zones or multicolor light. Then light energy is transformed into electrical energy in this optical semiconductor electrode. At this time it is changed into electrical energy very efficiently to light energy of visible light of not only ultraviolet radiation of a wavelength band below 300-400 nm but a 400-650-nm wavelength band.

[0051] Even visible light which cannot be used with metallic-oxide independent such as titanium oxide by using said optical semiconductor electrode in this invention can use effectively As a result synthetic use

of light such as sunlight is attained and light energy such as sunlight can be transformed into electrical energy at high efficiency. And in said optical semiconductor electrode to be used an adsorption film by at least one sort of said chemical very stable perylene derivative has adhered to a base material surface of said semiconductor firmly and this adsorption film. Since it is not easily desorbed from this optical semiconductor electrode, the characteristic of this optical semiconductor electrode is stabilized for a long period of time and can be maintained and can always perform a photoelectric conversion reaction efficiently.

[0052]

[Example] Hereafter, although the example of this invention is described, this invention is not limited to these examples at all.

[0053] (Example 1)

- 25 ml of production-alt. titanate acid tetraisopropyl of the optical semiconductor electrode was gradually added into the mixed solution of 150 ml of deionized water and the concentrated nitric acid 1.54g (specific gravity: 1.38) agitating violently. Temperature up was carried out to 80 °C, continuing churning further, more churning was continued at the temperature for 8 hours and the milky stable titanium oxide colloidal solution was obtained. The above operation was performed under the dry nitrogen air current. This colloidal solution was condensed until 40 ml of viscous fluids remained at 30 °C under decompression of 30 mmHg. In this way, the obtained viscous fluid was used as the titanium oxide colloidal solution.

[0054] Said titanium oxide colloidal solution was coated with the spin coat method on ITO/glass base material as an electrode and was calcinated at 500 °C for 1 hour. This operation was repeated 3 times and the titanium oxide enveloping layer about 1.0 micrometer thick was formed on this ITO/glass base material. When the crystal structure of the obtained titanium oxide enveloping layer was checked with the X-ray diffraction method, it was checked that it is a mixture of an anatase and a rutile type.

[0055] After 100 mg of mixtures and the potassium hydrate 0.5g of a perylene derivative which are expressed with said general formula (Ia-1) and a general formula (Ib-1) in ITO/glass base material in which said titanium oxide enveloping layer was formed are immersed in the solution which dissolved in 50 ml of ethanol at 70-80 °C for 1 hour, methanol, water and acetone -- subsequently with methanol, it was washed one by one and natural seasoning was carried out. Then the lead was connected to ITO/glass base material in which the titanium oxide enveloping layer is not formed, both terminal area was adhered with the epoxy resin and the

optical semiconductor electrode as shown in drawing 1 was produced. [0056] When the ultraviolet and visible absorption spectrum of the produced optical semiconductor electrode is investigated as shown in drawing 2 The same spectrum data as the ultraviolet and visible absorption spectrum by the mixture of the perylene derivative expressed with said general formula (Ia-1) and a general formula (Ib-1) is obtained. It was checked that the adsorption film by the mixture of the perylene derivative expressed with said general formula (Ia-1) and a general formula (Ib-1) on said titanium oxide enveloping layer is being fixed.

[0057] the optical semiconductor electrode 1 shown in drawing 1 -- the glass base material 2 top -- the ITO layer 3 and the titanium oxide enveloping layer 4 -- and laminating the adsorption film 5 by the mixture of the perylene derivative expressed with said general formula (Ia-1) and a general formula (Ib-1) in this order the end of these lamination sides and the terminal area with the lead 7 were covered with the epoxy resin as the adhesive agent 6 and have adhered with it.

[0058] - The optical semiconductor electrode 1 produced as mentioned above as shown in production-drawing 3 of a photoelectric conversion device. The platinum electrode selected as the counter electrode 9 and the saturation Calomel electrode selected as the reference electrode 10 were immersed in the electrolytic solution 11 in the transparent glass cell 13. Each electrode was connected to the potentiostat 12 using the lead 8 as a connecting means and the photoelectric conversion device was produced. As said electrolytic solution 11, 0.1M sodium sulfate / 0.02M potassium iodide solution was used. The lead 8 is connected to each electrode and energization has become possible. The lead 8 is accommodated in the glass tube. As the reference electrode 10, this photoelectric conversion device is equipped with the saturated calomel electrode so that energization is possible. The photoelectric conversion device was produced by the above.

[0059] - holding in the photoelectric conversion device obtained by more than photoelectric conversion reaction -- so that the potential of said optical semiconductor electrode may be set to 0V to said reference electrode -- white light (the xenon lamp of 500W.) It irradiated with illumination 4000lux or 550-nm monochromatic light (1 mW/cm²) from the back side of said optical semiconductor electrode. The value of the photoelectric current by the photoelectric conversion reaction produced at this time was measured with the potentiostat. The measurement result was shown in Table 2.

[0060] (Example 2) In Example 1 the mixture of the perylene derivative

expressed with said general formula (Ia-1) and a general formula (Ib-1) Like Example 1 the outside replaced with the mixture of the perylene derivative expressed with said general formula (Ia-3) and a general formula (Ib-3) produced the optical semiconductor electrode and the photoelectric conversion device respectively produced the photoelectric conversion reaction and measured photoelectric current. The measurement result was shown in Table 2.

[0061] (Comparative example 1) The outside which did not make the mixture of the perylene derivative expressed with said general formula (Ia-1) and a general formula (Ib-1) adsorb on said titanium oxide enveloping layer in Example 1 Like Example 1 the optical semiconductor electrode and the photoelectric conversion device were produced respectively the photoelectric conversion reaction was produced and photoelectric current was measured. The measurement result was shown in Table 2.

[0062] (Comparative example 2) It replaces with the mixture of the perylene derivative expressed with said general formula (Ia-1) and a general formula (Ib-1) in Example 1 Like Example 1 the outside which used 2457-tetraiodofluorescein (erythrosin B) produced the optical semiconductor electrode and the photoelectric conversion device respectively produced the photoelectric conversion reaction and measured photoelectric current. The measurement result was shown in Table 2.

[0063]

[Table 2]

[0064]

[Effect of the Invention] According to this invention many problems in said former are solvable. According to this invention the optical semiconductor electrode photoelectric conversion device and the photoelectric conversion method of it being efficiently available and excelling in photoelectric conversion efficiency stability endurance etc. and carrying out sunlight by low cost can be provided.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] Drawing 1 is a section approximate account figure of the optical semiconductor electrode in Example 1.

[Drawing 2] Drawing 2 is data of the ultraviolet and visible absorption spectrum of the optical semiconductor electrode in Example 1.

[Drawing 3] Drawing 3 is an approximate account figure of the photoelectric conversion device in Example 1.

[Description of Notations]

- 1 Optical semiconductor electrode
 - 2 Glass base material
 - 3 ITO layer
 - 4 Titanium oxide enveloping layer
 - 5 Adsorption film
 - 6 Adhesive agent
 - 7 Lead
 - 9 Counterelectrode
 - 10 Reference electrode
 - 11 Electrolytic solution
 - 12 Potentiostat
 - 13 Glass cell
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